SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2022……………………………………………………….……
Project Title:	Land surface-climate interactions in the EC-Earth ESM: their role for climate variability and contribution to future climate…………………………………………………….…… ………………………………………………………….……
Computer Project Account:	spsemay…………………………………………….………
Principal Investigator(s):	Wilhelm May…………………………………………….…… ………………………………………………………….……
Affiliation:	Centre of Environmental and Climate Science, Lund University, Sweden………………………………………….……
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………………….…… ………………………………………………………….……
Start date of the project:	1.1.2020…………………………………………….………
Expected end date:	31.12.2022………………………………………….………

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	9,000,000	0	9,000,000	0
Data storage capacity	(Gbytes)	70,000	49,000	95,000	49,000 (ecfs_status on ecgate)

Summary of project objectives (10 lines max)

I haven't performed any new (long) simulations but instead continued with the analysis of the shorter experiments with EC-Earth for the late observational period (1979-2017). In those simulations, the land-surface forcing, i.e. soil moisture and vegetation, had been obtained from an offline simulation with H-TESSEL+LPJG forced with ERA5. These simulations have the advantage that they cover a period with a wealth of observational data, e.g. soil moisture and surface flux estimates from remote sensing.

Summary of problems encountered (10 lines max)

The original plan of the special project has been in accordance with a proposal for an externally funded research project, which, unfortunately, has not been granted. In 2020, part of the proposed work could be done in another project and the simulations described in the progress report for 2021 had been performed. In 2021 and 2022 (so far) there were only resources left for analysing the existing simulations and publishing the results.

Summary of plans for the continuation of the project (10 lines max)

I will continue with the analysis of the existing simulations, focussing on the simulations for 1979-2017, and work on the publication of the results. I am working on one manuscript, where I (a) evaluate the quality of the simulations with HTESSEL+LPJG and EC-Earth (with the land-surface conditions prescribed) against observational data and (b) assess the role of the coupling with the atmosphere for the biases in the simulation with EC-Earth. I plan for another manuscript, where the impact of prescribing either soil moisture only, vegetation only or both for the biases in EC-Earth is investigated. Finally, the code development enabling the work of the project needs to be secured in the repository before the transfer to ATOS, also essential data need to be stored on the ecfs system.

List of publications/reports from the project with complete references

I have presented results from the analysis of the simulations with different model configurations for the period 1979-2017 at the Swedish Climate Symposium (poster, entitled 'The role of land-surface interactions for the climate biases in the EC-Earth earth system model') and I am preparing a manuscript for publication in Earth System Dynamics (see above).

Summary of results

As this is the third project year, this report summarises the results since July 2021, that is some examples from the analysis of simulations for 1979-2017 are given.

Figure 1 shows the geographical distribution of land-surface temperatures for boreal summer, i.e. in addition to the climatology for the reference data set ERA5 the differences between the offline simulation with the land module HTESSEL+LPJ-GUESS forced with ERA5 and ERA5 (LM – ERA5), between the simulation with the atmospheric component of EC-Earth with the land-surface conditions prescribed from the offline simulation and ERA5 (GCM – ERA5) and between the two simulations (GCM – LM). While the differences with the reference data set show the biases of the different model configurations, the difference between the land-surface module and the atmospheric component of EC-Earth illustrates the role of the coupling with the atmosphere for the bias. Figure 2, on the other hand, shows the distributions of the area-weighted differences with the reference data set and between the two simulations, respectively.

The simulation with the land-surface module is characterized by both positive and negative biases in land-surface temperatures (Fig. 1b) with a small overall positive bias (Fig. 2a). The positive biases mainly occur in the tropics and the Northern Hemisphere extratropics and the negative biases mainly in the subtropics. The simulation with the atmospheric component, on the other hand, shows predominantly negative biases but positive biases in the south-western part of North America, north-eastern Brazil and central Asia (Fig. 1c),

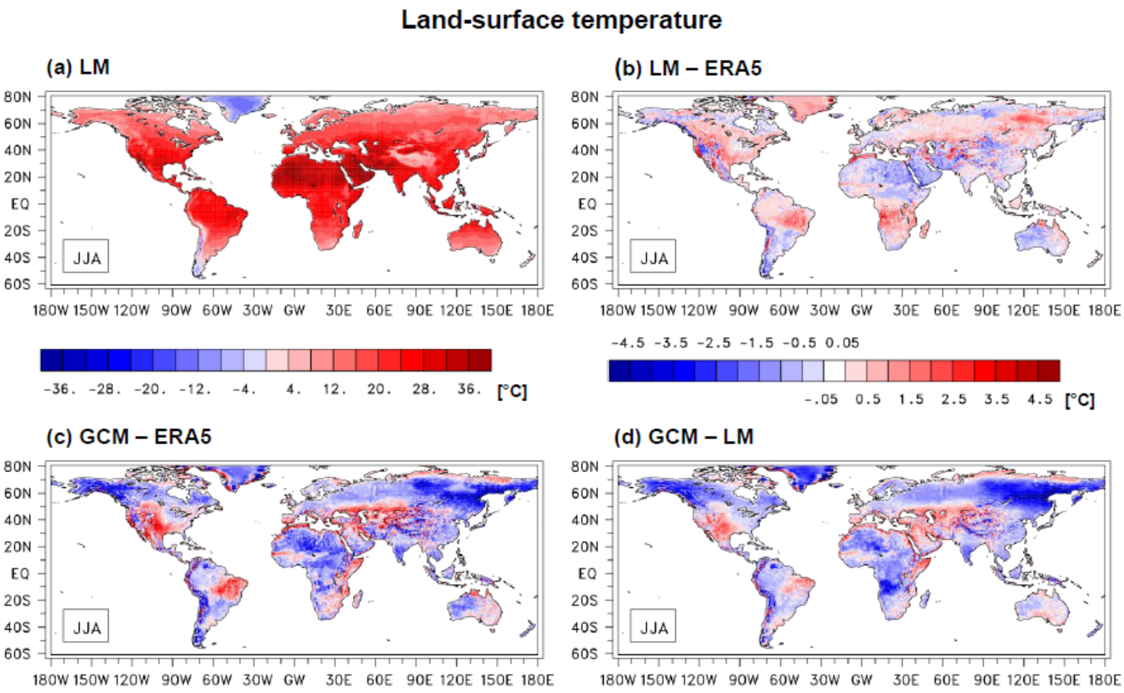


Fig. 1: Seasonal (June through August; JJA) mean values of land-surface temperatures for the simulation with the land component forced with ERA5 (LM) (a) as well as the differences (b) between LM and ERA5, (c) between the simulation with the atmospheric component of EC-Earth with the land-surface conditions prescribed from LM (GCM) and ERA5 and (d) between GCM and LM. Units are °C; the contour interval is 2 °C in (a) and 0.5 °C in (b-d), respectively.

resulting in a rather strong overall negative bias (Fig. 2b). Prescribing the land-surface conditions enhances the overall negative bias of EC-Earth, particularly by reducing the magnitude of the positive biases, which can be seen when comparing the respective distributions (Figs. 2b, c). Prescribing the land-surface conditions has only a small effect on the geographical distribution of the biases (Figs. 1c, d), indicating that the simulation of the atmospheric conditions by EC-Earth is the dominant driver of the regional biases in land-surface temperatures. The land-surface conditions, on the other hand, contribute with reducing the positive biases in the south-western part of North America, north-eastern Brazil and central Asia.

In the simulation with the atmospheric component of EC-Earth both soil moisture simulated by H-TESSEL as well as the vegetation simulated by LPJ-GUESS are prescribed. More precisely, the soil moisture in the three lowest levels of H-TESSEL is nudged towards the values from the offline simulation, while the soil moisture in the uppermost layer is not restricted. This approach was chosen to avoid artificial energy fluxes at the land surface when adding or removing soil moisture in the uppermost layer when nudging.

Both simulations area characterized by marked biases in surface soil moisture, namely too high soil moisture in the central tropics, Southeast Asia and at high northern latitudes and too low soil moisture in the extended subtropics, including the south-western part of North America, north-eastern Brazil and central Asia (Figs. 3b, c). These areas also show a warm temperature bias in EC-Earth. Overall, the offline simulation with the land module shows a small negative soil moisture bias (Fig. 4a), while the simulation with the atmospheric component of EC-Earth shows a slight positive bias (Fig. 4b). The local differences between the two simulations are relatively small but indicate a tendency that the coupling with the atmosphere enhances the biases in soil moisture (Fig. 3d).

The analysis was extended to the surface energy fluxes, distinguishing between the net radiation and the fluxes of sensible and latent heat as well as the evaporative fraction, which is defined as the ratio between the latent heat flux and the total energy flux, combing the latent and the sensible heat flux. To give a comprehensive picture of the biases in all components of the surface energy fluxes as well as in land surface temperatures and surface soil moisture, differences in the area means for the 44 land regions considered in CMIP6 were computed. Results for these regions are presented in Figures 5 and 6.

The simulation with the land-surface module is characterized by an underestimation of net radiation in

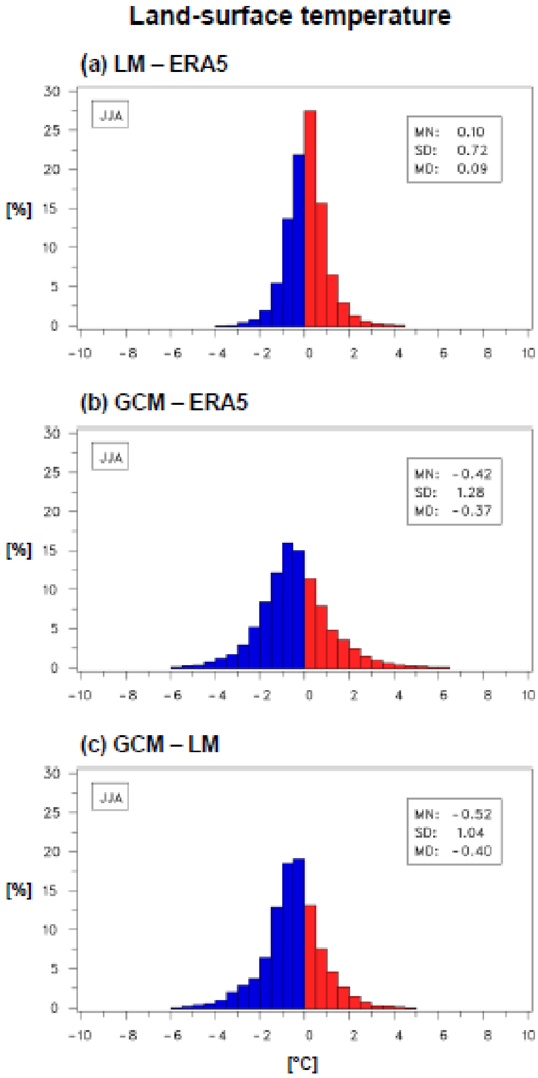


Fig. 2: Distribution of the area-weighted seasonal mean differences of land-surface temperatures (a) between LM and ERA5, (b) between GCM and ERA5 and (c) between GCM and LM. Units are °C on the abscissa and % on the ordinate, respectively. The mean, standard deviation and median of the distribution are given in the box, units are °C.

almost all of the regions (Fig. 5a), meaning that too little radiation is emitted to the atmosphere. Also the fluxes of sensible heat are underestimated in the majority of the regions, with the exception of Africa with an overestimation of the sensible heat flux over most of the continent. In contrast, the fluxes of latent heat are overestimated in the majority of the regions, again most of the African continent showing the opposite behaviour, namely an underestimation of the latent heat fluxes. Thus, in the majority of the regions an over-/underestimation of the sensible heat fluxes is associated with too weak/strong fluxes of latent heat. As a result, the evaporative fraction is too high in most regions, with the exception of the African continent. The differences in the corresponding regional mean values suggest on one hand a link between the biases in soil moisture and in the fluxes of latent heat, with biases in soil moisture being associated with biases of the same sign in latent heat fluxes, and on the other a relation between the biases in the evaporative fraction and in land-surface temperatures, with biases in the evaporative fraction being associated with biases of the opposite sign in land-surface temperatures.

In contrast to the simulation with the land-surface module, in the simulation with the atmospheric component of EC-Earth the net radiation does not show such a clear tendency, as net radiation is overestimated in about half of the regions (Fig. 5b). The tendency of underestimating the fluxes of sensible heat in most of the regions as well as of overestimating latent heat fluxes and the evaporative fraction, on the other hand, is similar to the offline simulation. The regional mean biases in land-surface temperatures are generally more pronounced in the simulation with EC-Earth than in the simulation with the land-surface module, in particular in the regions with too cold temperatures.

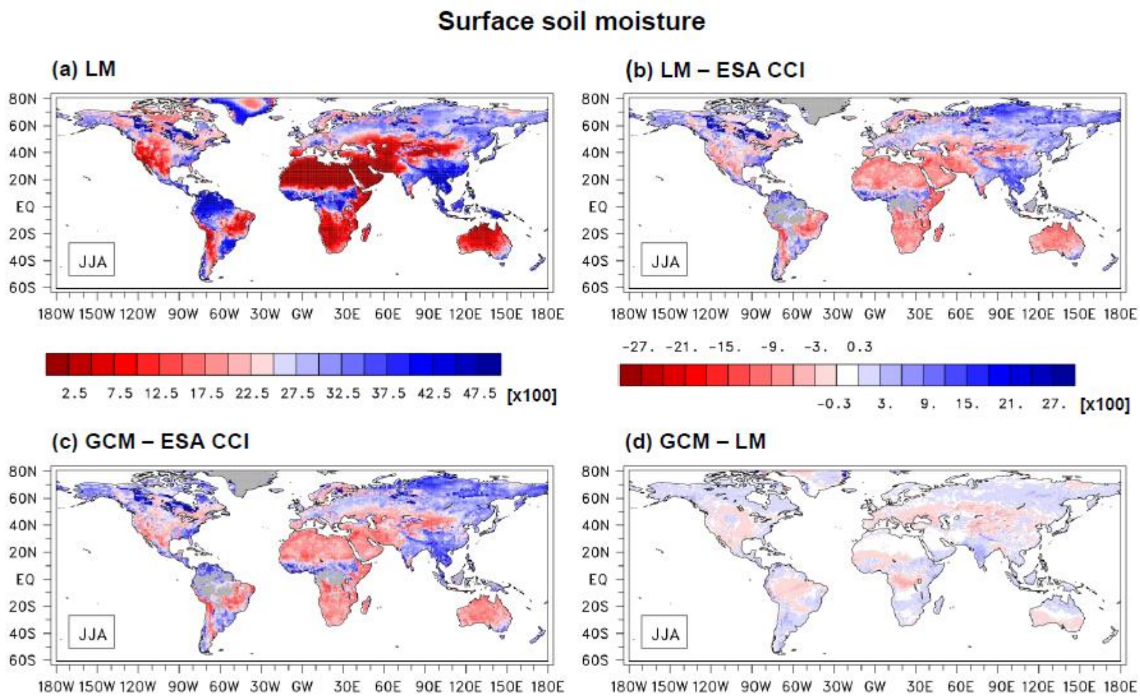


Fig. 3: Seasonal mean values of surface soil moisture (volumetric soil water) for the simulation with the land component forced with ERA5 (LM) (a) as well as the differences (b) between LM and ESA-CCI, (c) between the simulation with the atmospheric component of EC-Earth with the land-surface conditions prescribed from LM (GCM) and ESA-CCI and (d) between GCM and LM. Units are m^3/m^3 (x100); the contour interval is 2.5 m^3/m^3 (x100) in (a) and 3 m^3/m^3 (x100) in (b-d), respectively.

The regional mean differences between the two simulations clearly indicate a general tendency of stronger net radiation and stronger fluxes of sensible heat in the simulation with the atmospheric component of EC-Earth (Fig. 6). The corresponding differences in latent heat fluxes, on the other hand, do not reveal such a clear tendency, with about half of the regions showing positive or negative differences, respectively. These differences in the two components of the surface energy fluxes result in lower values of the evaporative fraction in the simulation with EC-Earth in most of the regions. This indicates a systematic effect of the coupling with the atmosphere on the partition of the energy fluxes at the land surface. However, the pronounced negative bias in the land-surface temperatures in EC-Earth appears not to be related to the biases in the partition of the surface energy fluxes, e.g. the partition between the latent and sensible heat fluxes.

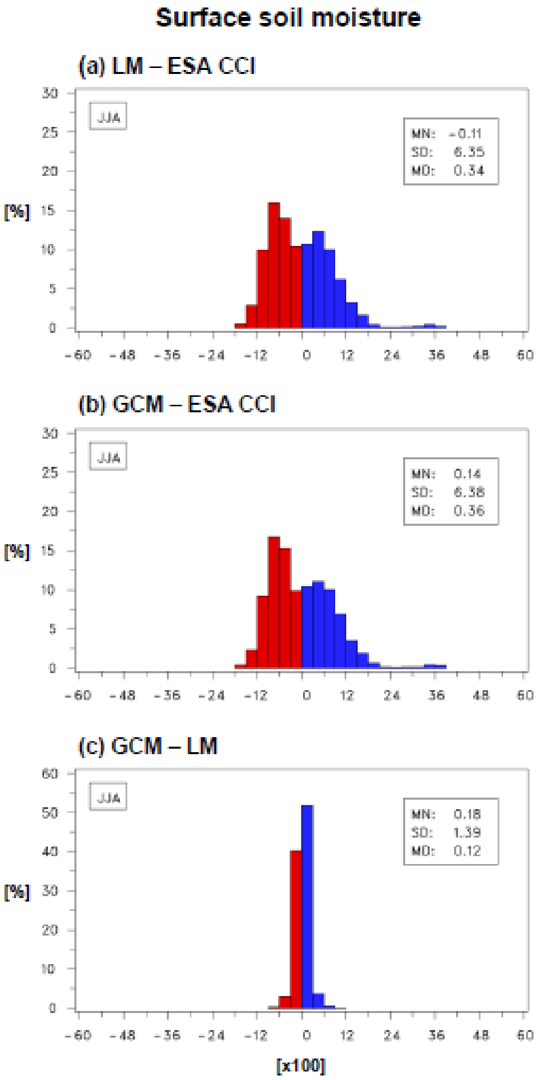
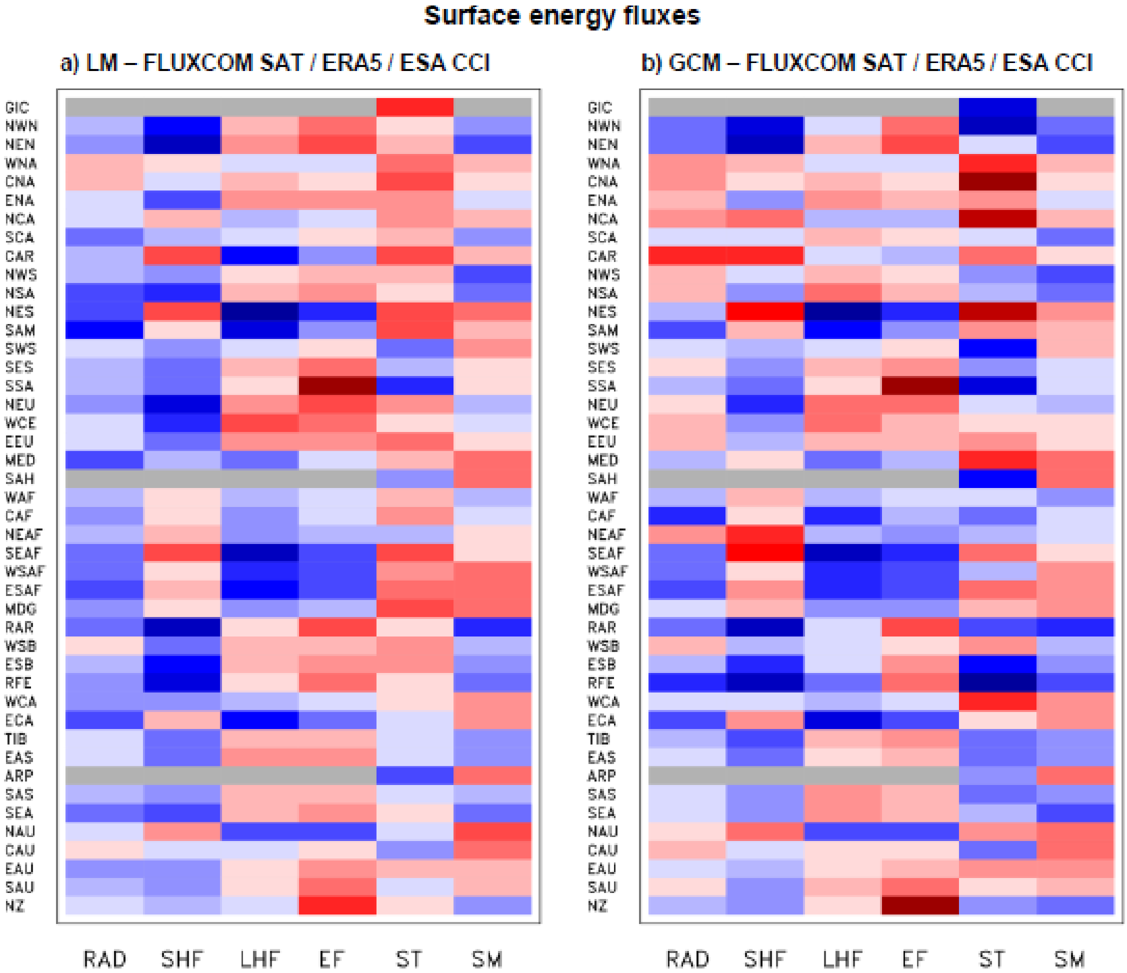


Fig. 4: Distribution of the area-weighted seasonal mean differences of surface soil moisture (a) between LM and ESA-CCI, (b) between GCM and ESA-CCI and (c) between GCM and LM. Units are m^3/m^3 (x100) on the abscissa and % on the ordinate, respectively. The mean, standard deviation and median of the distribution are given in the box, units are m^3/m^3 (x100).



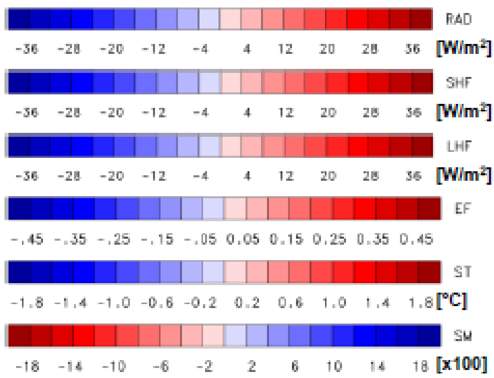


Fig. 5: Differences in the regional seasonal means of surface energy fluxes, i.e. net radiative flux (RAD), fluxes of sensible (SHF) and latent heat (LHF) and evaporative fraction (EF), as well as land-surface temperature (ST) and surface soil moisture (SM) between the two simulations and the corresponding reference data set, i.e. ERA5 for ST, ESA-CCI for SM and FLUXCOM (utilizing satellite data only) for the surface energy fluxes. The units and contour intervals can be seen in the corresponding bars.

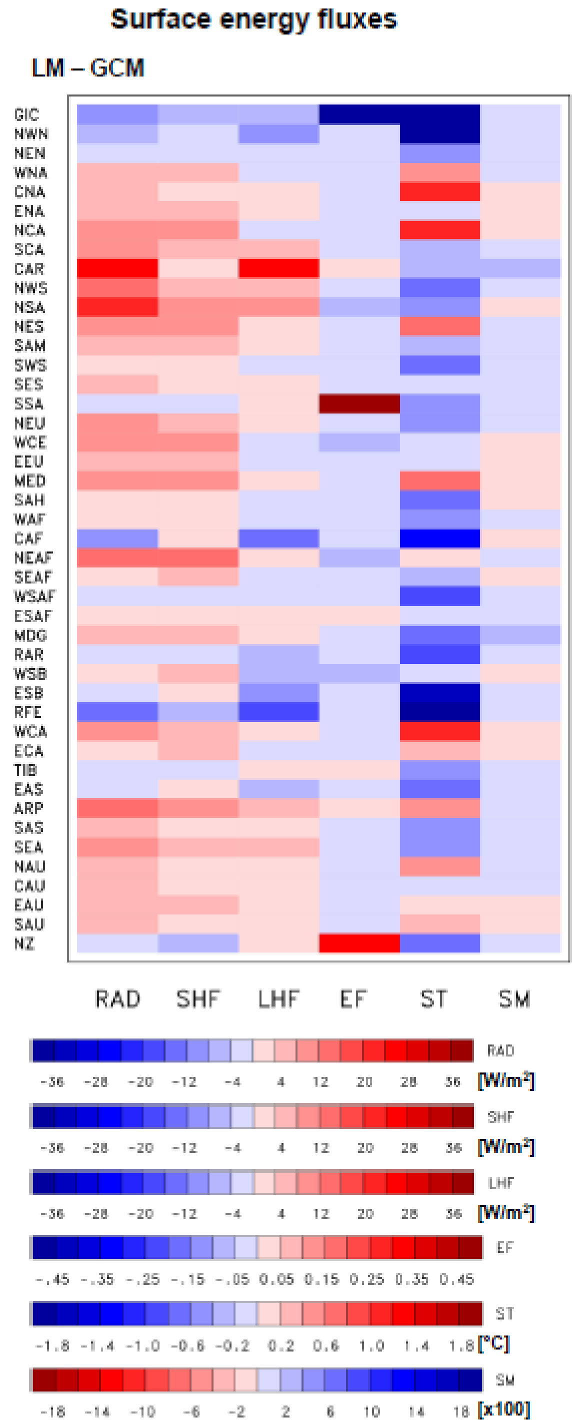


Fig. 6: Differences in the regional seasonal means of surface energy fluxes, as well as land-surface temperature and surface soil moisture between the two simulations. The units and contour intervals can be seen in the corresponding bars.